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Farnborough, Hants.

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MEASUREMENTS OF BENDING MOMENT ON A MODEL TAILLESS GLIDER WING

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SUMMARY

Bending moment at the wing root and total lift have been measured on a model wing for the General Aircraft tailless glider (V plan form and 28.4° sweep back). The tests included measurements of the effects of flap and elevon deflection and of end fins. The span loading due to incidence has been deduced from the results.

The bending moments and span loading have been compared with estimates based on Schrenk's approximate method and in some cases with Falkner's more rigorous method. Schrenk's method appears, on the whole, to be reliable enough for a first estimate of load distribution in the early stages of design and to show the effects of major modifications on wings of not too large sweep back. For a final estimate Falkner's method is more accurate.

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1 Introduction

The problem of determining the spanwise lift distribution on a swept back wing is a fundamental one in the estimation of the characteristics of tailless aircraft. The model tests described in this note provide an overall check on the accuracy of estimated distributions. The total lift and the bending moment on one wing about a chordwise axis at the root have been measured on a model of a tailless glider. The results are compared with estimated bending moments due to a change of incidence and at no lift for the plain wing and with elevons and flaps deflected in turn (para. 3).

It is also possible (para. 4) to calculate the lift distribution due to a change of incidence directly from the lift and moment measurements, on the assumption that it is given by a two term Fourier Series. For the no-lift distribution, at least with flaps and elevons deflected, more terms in the series are required and these can be determined only from bending moment measurements at several sections along the span.

2 Description of tests

The tests were made in the R.A.E. No. 1 $11\frac{1}{2} \times 8\frac{1}{2}$ ft. tunnel (with honeycomb) during March 1944 on a 1/5.67 scale model of the General Aircraft glider wing of V plan form and 28.4° sweep back. Details of the model are given in Table I and Fig. 1.

Total wing lift and bending moment about a chordwise axis AA at 0.066 semi-span from the plane of symmetry were measured (Fig. 1). The rig used for the measurements of bending moments was identical with that used in similar tests on a non-swept back wing described in Ref. 5. The tests were made with a sealed gap of 0.03 ins. at the bending moment axis and it was verified that this gap did not affect the total wing lift at any given incidence.

The following conditions were covered by the tests:-

(a) plain wing, elevons sealed$^{\phi}$; $\eta = 15°, 10°, 0°, -10°, -15°$.

(b) wing with end fins, elevons sealed; $\eta = 0°$.

(c) wing with split flap at 60°, elevons sealed; $\eta = 15°, 0°, -15°$.

(d) plain wing, elevons unsealed; $\eta = 0°$.

All the tests were made at a wind speed of 120 ft./sec., corresponding to a Reynolds number of 1.03×10^6 based on mean wing chord. The usual tunnel constraint corrections were applied*.

ϕ The method of sealing the elevons in the tests was to fair the elevon gap completely so as to form a continuous, smooth wing contour.

* A theoretical estimate has been made of the tunnel interference corrections to the forces and moments on a swept back wing, and it has been found that they are little different from the usual corrections. In particular it has been established that the span loading distribution is sensibly unaffected by the tunnel constraint.

3 Comparison of measured and estimated bending moments

3.1 Plain wing, without fins, with flaps and elevons neutral

For a wing at moderate angles of incidence the lift distribution can be split up into two parts. The first depends upon the plan form and is proportional to the incidence measured from no lift; the second is dependent upon twist and represents the loading at zero lift. It is convenient therefore to consider separately the bending moments due to these two parts and to examine

(1) the rate of change of bending moment with lift due to changing incidence,

(2) the bending moment at zero lift.

The experimental values are taken from Fig. 3 and the estimated values are based on two theoretical methods,

(1) Schrenk's method as modified by Neumark[3],

(2) Falkner's lifting plane method[4].

The first is a very simple approximate method which neglects the change in lift distribution due to sweep back. The second includes this effect and is a more rigorous methodm but it is much more laborious to apply. The results are compared in the following table; C_{BM} is the coefficient of the bending moment at the root based on total wing area and span:-

	Measured	Schrenk/ Neumark	Falkner	Falkner without sweep back
dC_{BM}/dC_L	0.092	0.089	0.091	0.089
C_{BM_0}	-0.001	-0.0034	-0.0029	-

For dC_{BM}/dC_L Falkner's method agrees very well with experiment and the discrepancy with the Schrenk method is only 3%, attributable to the effect of sweep back on lift distribution.

The order of agreement on C_{BM_0} is not so good, but the values are all small in comparison with the moments produced by flaps and elevons (Fig. 3). The discrepancy may be due to a lack of symmetry in the model or in the tunnel stream. It is seen, for instance, from Fig. 3 that $C_{BM} = -0.003$ would correspond to a C_L of -0.025 on the same wing. Thus, from Fig. 2a, effective incidence changes of $\pm 0.3°$ on the two wings could account for the difference. The order of agreement between the two theoretical methods is very good.

3.2 Effect of tip fins

The effect of end fins is to increase the lift near the tip at a given incidence. Thus both $dC_L/d\alpha$ and dC_{BM}/dC_L are increased, as shown in Figs. 2b and 4. In this case only the Schrenk method is available for comparison, as no calculations by Falkner's method have been done for this wing with end fins. The Schrenk method makes no allowance for fin effect on C_{BM_0} and there is no appreciable effect shown in the experiments. The measured and estimated increments in dC_{BM}/dC_L are 0.008 and 0.005 respectively giving total values of 0.100 and 0.094 (Schrenk).

3.3 Effect of flaps and elevons

The Schrenk method is applied in Refs. 6,7 to the estimation of the effect of flaps and elevons. It is there assumed that elevons or split flaps in the normal position (trailing edges of flap and wing coinciding in the closed position) have no effect on lift distribution due to a change in incidence, and therefore no effect on $dC_L/d\alpha$ and dC_{MB}/dC_L. For moderate elevon angles and incidences this is confirmed by Figs. 2a and 3, and for flaps at 60° with elevons 0° by Figs. 2b and 4.

The main effect of elevons or flaps is to change the lift distribution at zero lift and the incidence for zero lift. In the following table the measured and estimated values of $\Delta C_{BM_0}/\Delta C_L$ are compared, ΔC_{BM_0} being the increment in bending moment coefficient at zero lift and ΔC_L the increment in C_L at a given incidence.

		Measured	Schrenk method
$\Delta C_{BM_0}/\Delta C_L$	Elevons -10°	0.050	0.046
	Flaps 60°	-0.035	-0.035

The order of agreement is good, considering the simple assumptions made in the Schrenk method.

4 Lift distribution

4.1 Loading due to a change of incidence

The lift distribution can be calculated directly from the lift and bending moment measurements on the assumption that it is given by a two term Fourier series. The circulation Γ, at any section of the wing is expressed in the form,

$$\frac{\Gamma}{\frac{1}{2}U\bar{c}} = \frac{dL/d\theta}{\frac{1}{2}\rho U^2 s\bar{c}\sin\theta} = \alpha\sum_{1}^{\infty} A_n \sin n\theta, \tag{1}$$

where
- U = the free stream velocity
- L = the total lift on the wing
- $\bar{c}$ = mean chord
- α = incidence measured from the no-lift direction of the complete wing
- θ is defined by $x/s = z = -\cos\theta$
- s = semi-span
- x = distance outboard of plane of symmetry.

For a symmetrical wing only odd values of n are admissible in equation (1).

The bending moment M about a chordwise axis distant x_1 from the plane of symmetry is given by,

$$M - M_o = \int_{\phi}^{\pi} s(\cos\phi - \cos\theta)\,\frac{dL}{d\theta}\,d\theta \qquad (2)$$

where M_o is the bending moment at no lift and $-\cos\phi = x_1/s$.

The following relations can be deduced from (1) and (2),

$$A_1 = \frac{4}{\pi}\frac{dC_L}{d\alpha} \qquad (3)$$

$$\frac{dC_{BM}}{dC_L} = \frac{1}{2\pi}\left\{(\pi - \phi + \frac{\sin 2\phi}{2})\cos\phi - \tfrac{1}{2}(\frac{\sin 3\phi}{3} - \sin\phi)\right.$$

$$\left. - \frac{A_3}{A_1}\left[(\sin 2\phi - \frac{\sin 4\phi}{2})\;\frac{\cos\phi}{2} + \frac{1}{2}(\frac{\sin 5\phi}{5} - \sin\phi)\right] + \dots\right\} \qquad (4)$$

Two relations are available for solving (3) and (4) from the measurements of lift and of bending moment about a single chordwise axis; hence only A_1 and A_3 can be determined. A similar method has been used in Ref.5 on non-swept back wings and theoretical estimates of spanwise loads suggest that the higher harmonics have little significance.

The lift distribution, deduced in this way, is plotted in Fig.5, where it is compared with an elliptical loading and with the distributions estimated by Schrenk's and Falkner's methods. It is seen that it agrees very well with the Falkner curve and is quite close to the elliptical loading curve. The Schrenk curve shows appreciable differences particularly at the wing root.

4.2 Loading at zero lift

The circulation distribution at zero lift may be expressed in the same form as (1) above.

$$\frac{\Gamma}{\frac{1}{2}U\bar{c}} = \frac{dL/d\theta}{\frac{1}{2}\rho U^2 s\bar{c}\,\sin\theta} = \sum_{3}^{\infty} B_n \sin n\theta. \qquad (5)$$

The bending moment coefficient at zero lift is given by

$$C_{BM_o} = \left\{\frac{B_3}{4}\left[\frac{\cos\phi}{2}\;(\frac{\sin 4\phi}{2} - \sin 2\phi) + \tfrac{1}{2}(\sin\phi + \frac{\sin 5\phi}{5})\right] + \dots\right\} \qquad (6)$$

With a single cut only B_3 can be determined but this should give the no-lift distribution with sufficient accuracy for the plain wing with twist. Falkner's method gives the following values for B_3 etc. due to 5^o twist on this wing:-

$$B_3 = -0.0598, \quad B_5 = -0.00215, \quad B_7 = 0.0000,$$

thus confirming the relative unimportance of B_5 etc. With elevons and flaps deflected the higher harmonics cannot be neglected.

For a reliable assessment of B_3 from experimental results it is apparent from para. 3.1 that the lift must be measured on the half-wing to eliminate the effect of asymmetry.

5 Conclusions

The Schrenk method of estimating lift distribution tends to under estimate the bending moment at the wing root, because it makes no allowance for the effect of sweepback. In the case examined here the error is only 3% in dC_{BM}/dC_L without fins and 6% with large fins at the wing tips. The discrepancy will increase with angle of sweepback. Falkner's method gives very good agreement without fins, but no estimated results are available for comparison with fins.

The bending moment increments due to flaps and elevons, for given increments in lift agree fairly well with those estimated by Schrenk's method[6,7]. No calculations have been made by Falkner's method for this wing.

On the whole it appears that Schrenk's method is good enough to give an approximate estimate in the design stage and to show the effect of major modifications on load distribution, provided the sweepback angle is not too large (< 30°). For a final estimate Falkner's method is more accurate. In its original form it is too laborious for frequent use, but a simpler form of it has now been developed.

List of Symbols

$A_1, A_2 \ldots A_n$	coefficients in the Fourier series for loading due to a change of incidence (see 4.1 (1)).
$B_1, B_2 \ldots B_n$	coefficients in the Fourier series for loading at zero lift (see 4.2 (5)).
c	chord at any section
$\bar{c}$	mean chord
L	wing total lift
C_L	lift coefficient
ΔC_L	increment in C_L at a given incidence
M	bending moment
M_o	bending moment at zero total lift
C_{BM}	bending moment coefficient $M/\frac{1}{2}\rho U^2(2s)^2\bar{c}$
C_{BM_o}	bending moment coefficient at zero total lift
ΔC_{BM_o}	increment in C_{BM_o}

List of Symbols (contd.)

s	semi-span
S	total wing area
U	free stream velocity
x	spanwise distance outboard of plane of symmetry
x_1	spanwise distance of bending moment axis from plane of symmetry
$z =$	x/s
α	incidence measured from no-lift direction of the whole wing
Γ	circulation at any section
θ	defined by $x/s = z = - \cos \theta$
ϕ	value of θ at bending moment axis, $- \cos \phi = x_1/s$
ρ	density of air.

List of References

No.	Author	Title, etc.
1	V.M.Falkner	The calculation of aerodynamic loading on surfaces of any shape. R.& M. 1910 (A.R.C.6997) Aug.1943.
2	O.Schrenk	A simple approximate method for obtaining the spanwise lift distribution. N.A.C.A. T.M. No.948 Jour. Roy. Aero. Soc. No.370. Oct.1941.
3	S.Neumark	Analysis of the longitudinal stability of tailless and tail first aircraft. R.A.E. Report No. Aero.1859. Sept. 1943.
4	V.M.Falkner	Comparison of the simple calculated characteristics of four swept back wings. A.R.C.7446. Feb.1944.
5	H.V.Becker, H.B.Squire and C.Callen	The effect of fuselage and nacelles on wing bending moment, shear and torsion. R.A.E. Report No. Aero.1886. Nov.1943.
6	M.M.Dent and M.F.Curtis	A method of estimating the effect of flaps on pitching moment and lift on tailless aircraft. R.A.E. Report No. Aero.1861. Sept.1943. A.R.C.7270.

List of References (contd.)

No.	Author	Title, etc.
7	J.A.H. Shepperd	A method of estimating the effect of elevons on pitching moment and lift on tailless aircraft. R.A.E. Report No. Aero.1916. Feb.1944.
8	V.M. Falkner	The effect of sweep back on the aero-dynamic loading on a V wing. A.R.C.7786. June, 1944.

Attached:

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Tables I, II and III

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A.D.A.R.D.(Res.)		
A.D.R.D.L.1.	(2)	
A.D.R.D.L.2.	(2)	
R.T.P./T.I.B.	(110 + 1)	
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A.& A.E.E.	(2)	
A.R.C.	(36)	
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Tailless Committee (per D.D.G.S.R.)		(20)
Mr. Falkner N.P.L.		(1)

Table I

Model data and full scale dimensions

Scale = 1/5.67

Wing gross area	S	351.5 sq.ft.
Span	2s	45.36 ft.
Mean chord	$\bar{c}$	7.74 ft.
Plane of measurement of bending moments (measured spanwise from centre line of aircraft)		1.498 ft.
Total fin area	S_F	18.8 sq.ft.
Flaps:		
Type		Split
Span		10.19 ft.
Chord: Root		2.27 ft.
Tip		1.63 ft.

Table II

Bending moments for plain wing with elevons sealed

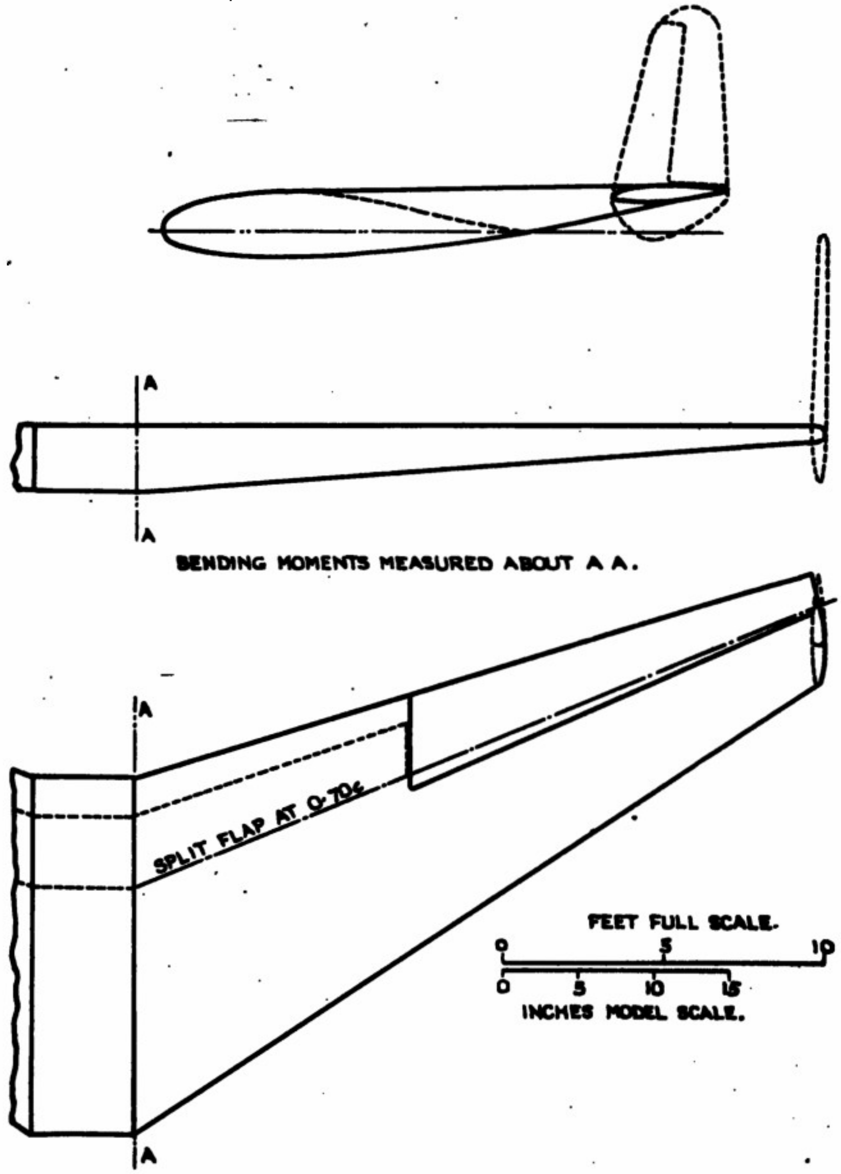
WING ALONE														
$\eta = 15^\circ$			$\eta = 10^\circ$			$\eta = 0^\circ$			$\eta = -10^\circ$			$\eta = -15^\circ$		
α	C_L	C_{BM}	α	C_L	C_{BM}	α	C_L	C_{BM}	α	C_L	C_{BM}	α	C_L	C_{BM}
-2.05	0.145	0.0252	-4.25	-0.114	-0.0135	-2.3	-0.149	-0.0144	-0.25	-0.174	-0.0257	-0.25	-0.243	-0.0357
0.15	0.308	0.0394	-2.05	0.047	0.0128	-0.95	-0.050	-0.0052	1.9	-0.024	-0.0120	0.15	-0.221	-0.0339
2.15	0.445	0.0504	0.1	0.209	0.0278	-0.1	0.009	0.0002	4.0	0.131	0.0028	1.8	-0.113	-0.0252
4.35	0.588	0.0610	2.25	0.368	0.0426	0.95	0.092	0.0078	6.2	0.295	0.0180	4.0	0.034	-0.0111
6.45	0.726	0.0717	4.3	0.522	0.0560	2.1	0.171	0.0154	9.35	0.536	0.0405	6.05	0.190	0.0038
9.55	0.932	0.0867	6.4	0.665	0.0680	3.1	0.251	0.0229	12.4	0.762	0.0609	9.2	0.439	0.0270
12.75	1.115	0.0986	9.45	0.867	0.0839	4.1	0.326	0.0297	15.6	0.959	0.0754	12.4	0.670	0.0484
15.75	1.243	0.1034	12.7	1.055	0.0960	5.15	0.409	0.0374	18.7	1.072	0.0792	15.55	0.891	0.0672
18.95	1.334	0.1049	15.85	1.187	0.1011	6.25	0.493	0.0453	21.1	1.155	0.0828	18.65	1.013	0.0722
21.95	1.412	0.1048	18.9	1.280	0.1034	7.35	0.568	0.0517				21.7	1.106	0.0770
			21.95	1.370	0.1044	9.4	0.717	0.0639						
						12.65	0.926	0.0780						
						15.7	1.063	0.0832						
						18.85	1.175	0.0875						
						21.85	1.269	0.0900						

Table III

Bending moments for wing with flaps, elevons and end fins

WING ALONE			WING + END FINS			WING + FLAPS					
$\eta = 0^\circ$ (unsealed)			$\eta = 0^\circ$ (sealed)			$\eta = 0^\circ$ (sealed)			$\eta = 15^\circ$ (sealed)		
α	C_L	C_{BM}	α	C_L	C_{BM}	α	C_L	C_{BM}	α	C_L	C_{BM}
-2.2	-0.137	-0.0135	-2.2	-0.154	-0.0156	-1.75	0.383	0.0209	-1.6	0.698	0.0632
-0.1	0.012	0.0002	-0.1	0.009	0.0004	0.2	0.527	0.0348	0.5	0.831	0.0742
2.0	0.164	0.0143	2.05	0.176	0.0169	2.4	0.677	0.0491	2.6	0.956	0.0828
4.2	0.319	0.0284	4.15	0.348	0.0336	4.5	0.819	0.0629	4.7	1.079	0.0916
6.25	0.468	0.0416	6.3	0.515	0.0498	6.65	0.971	0.0774	6.75	1.197	0.1007
9.40	0.681	0.0600	9.45	0.744	0.0686	9.8	1.184	0.0942	9.95	1.367	0.1125
12.55	0.882	0.0764	12.7	0.949	0.0824	11.9	1.357	0.1045	13.0	1.498	0.1186
15.70	1.037	0.0848	15.7	1.086	0.0880	16.05	1.489	0.1103	16.1	1.579	0.1210
18.65	1.155	0.0897	18.7	1.188	0.0902	17.4	1.389	-	19.1	1.562	0.1135
21.85	1.257	0.0930	21.9	1.284	0.0924						

FIG. 1.



G.A.L. TAILLESS.
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FIG. 2.

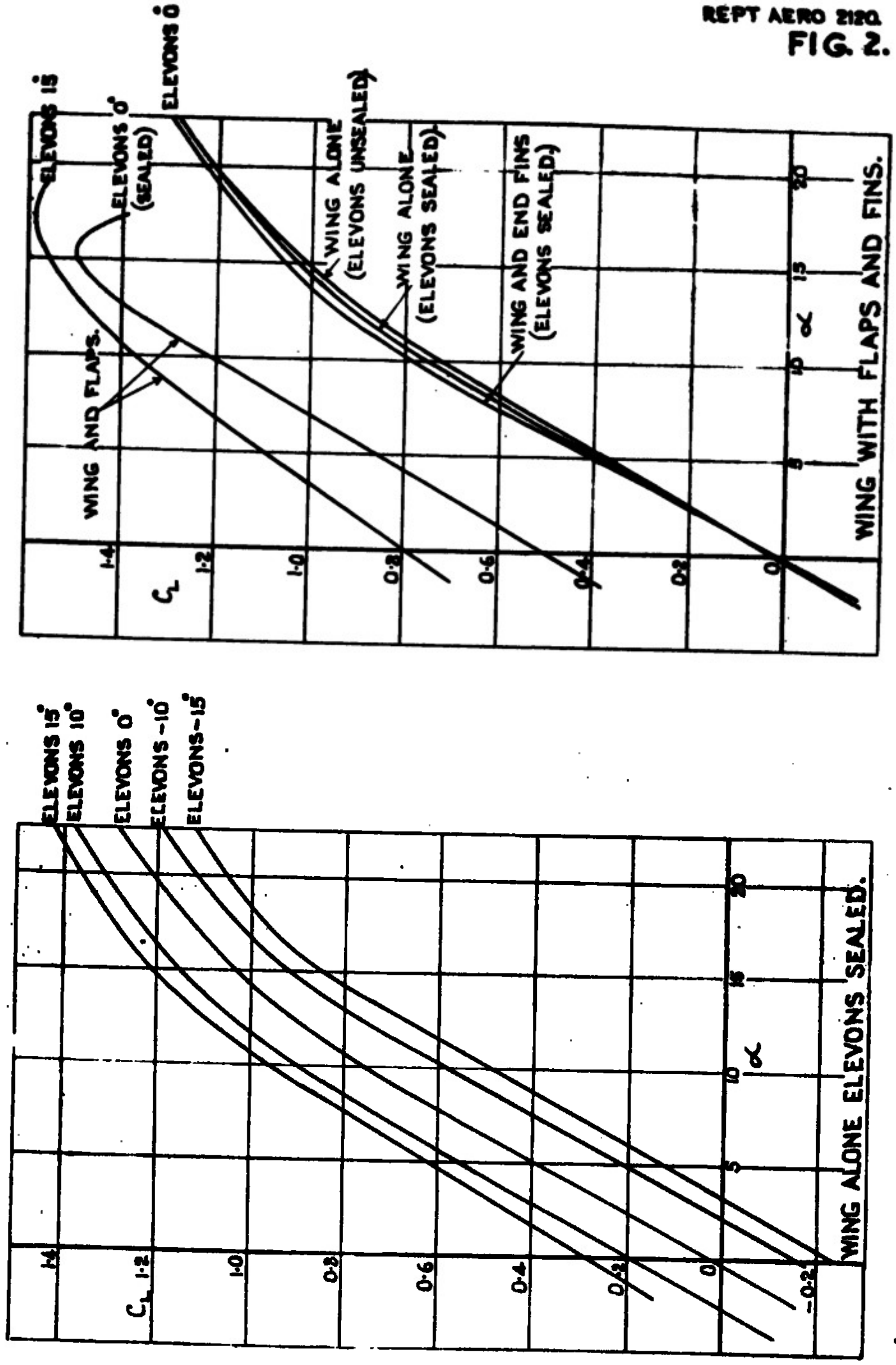

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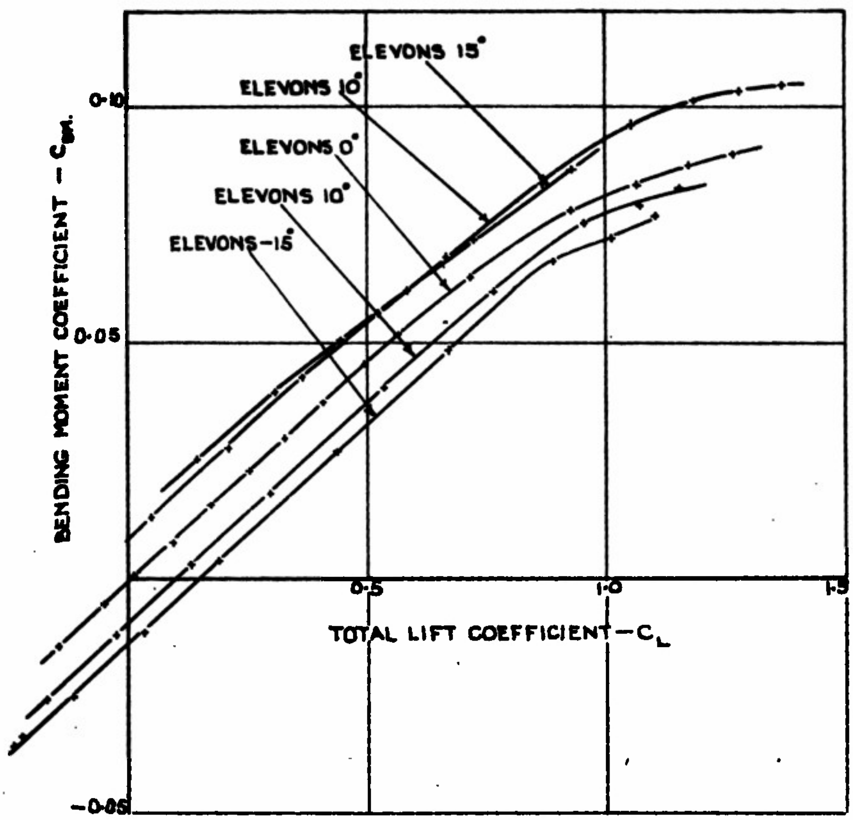
FIG.3.



BENDING MOMENTS FOR WING ALONE
ELEVONS SEALED.

[TABLE 2]

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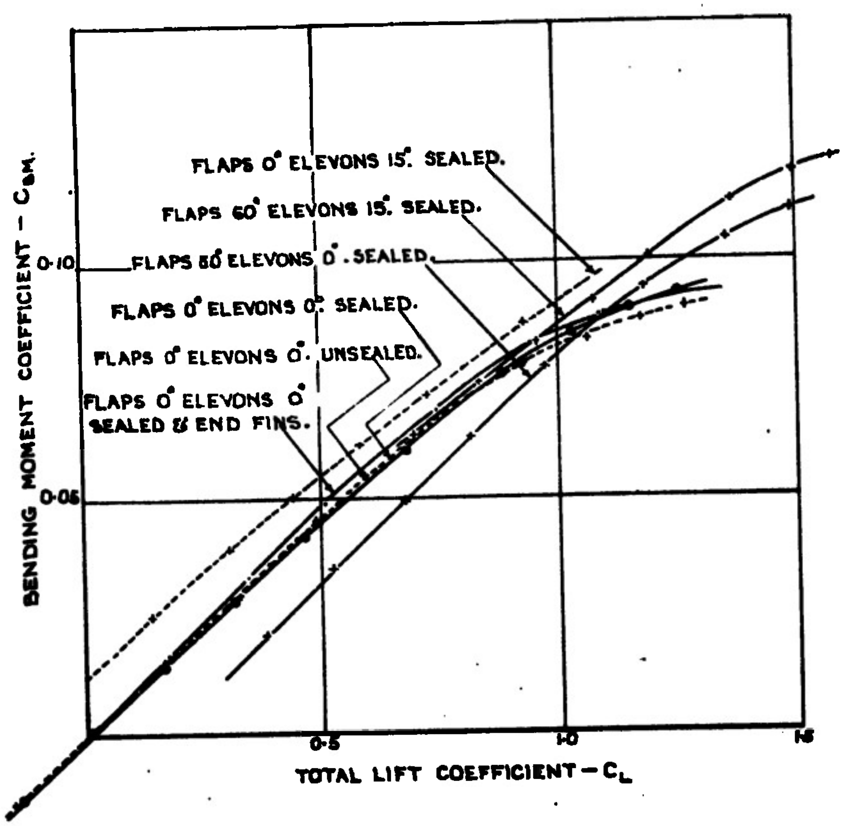
FIG. 4.



BENDING MOMENTS FOR WING WITH FLAPS FINS AND DEFLECTED ELEVONS.

(SHOWING EFFECT OF SEALING ELEVONS).

[TABLE 3]

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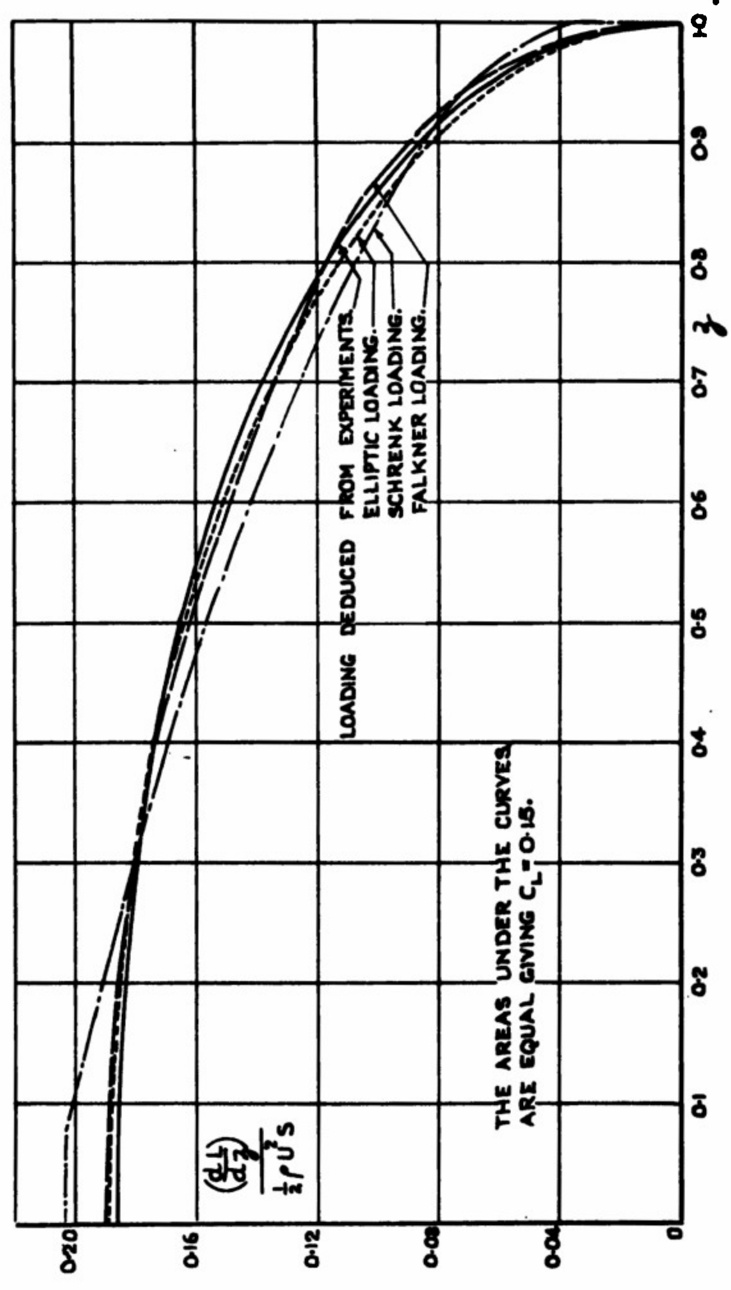
FIG. 5.



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TITLE: Measurements of Bending Moment on a Model Tailless Glider Wing

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